GLUON SATURATION AND INITIAL CONDITIONS

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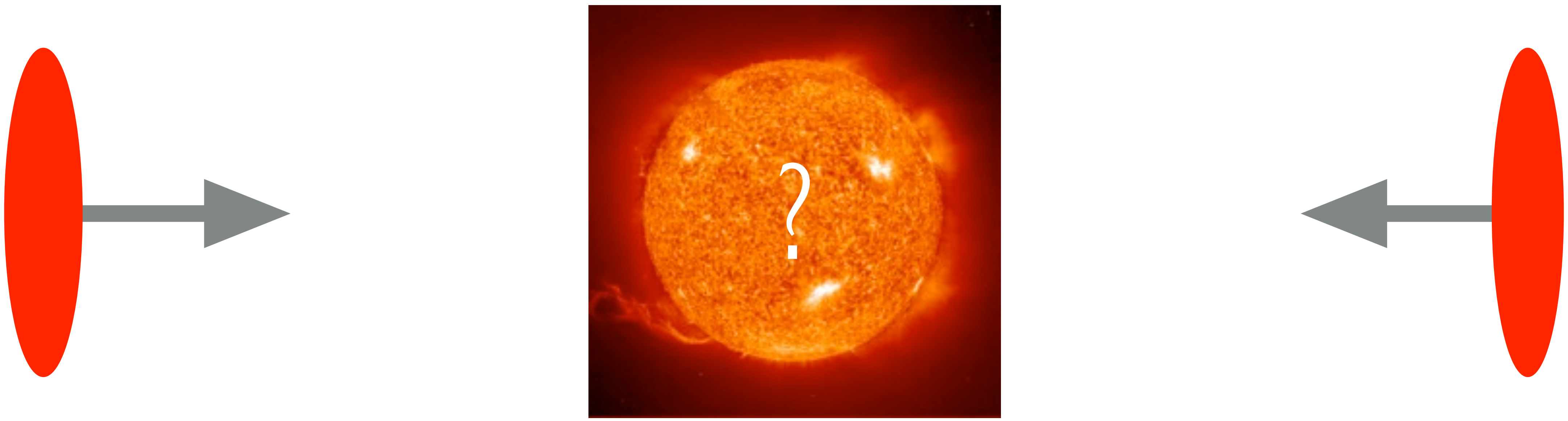
Nuclei as heavy as bulls through collision generate new states of matter

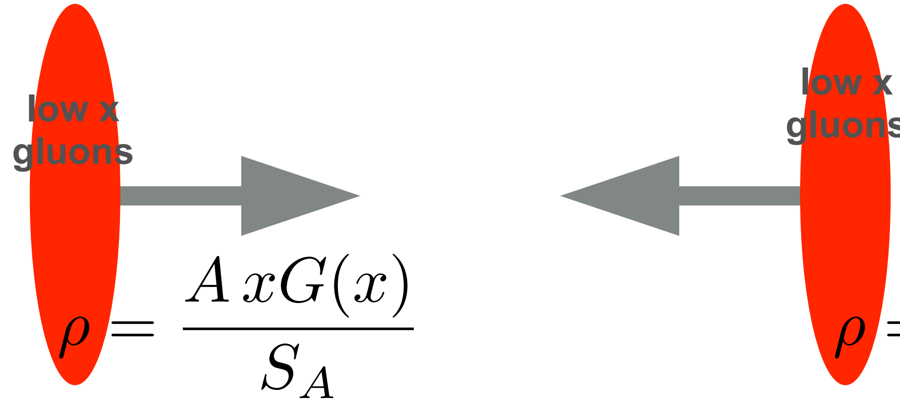
PHENIX Collaboration Meeting, Ames IA, 7/12/2010



What are the properties of the nuclear matter ?

Cold nuclear matter ⇒ Hot medium

CGC = THEORY OF GLUON SATURATION



$$\rho = \frac{A\,xG(x)}{S_A} \qquad \rho = \frac{A\,xG(x)}{S_A}$$

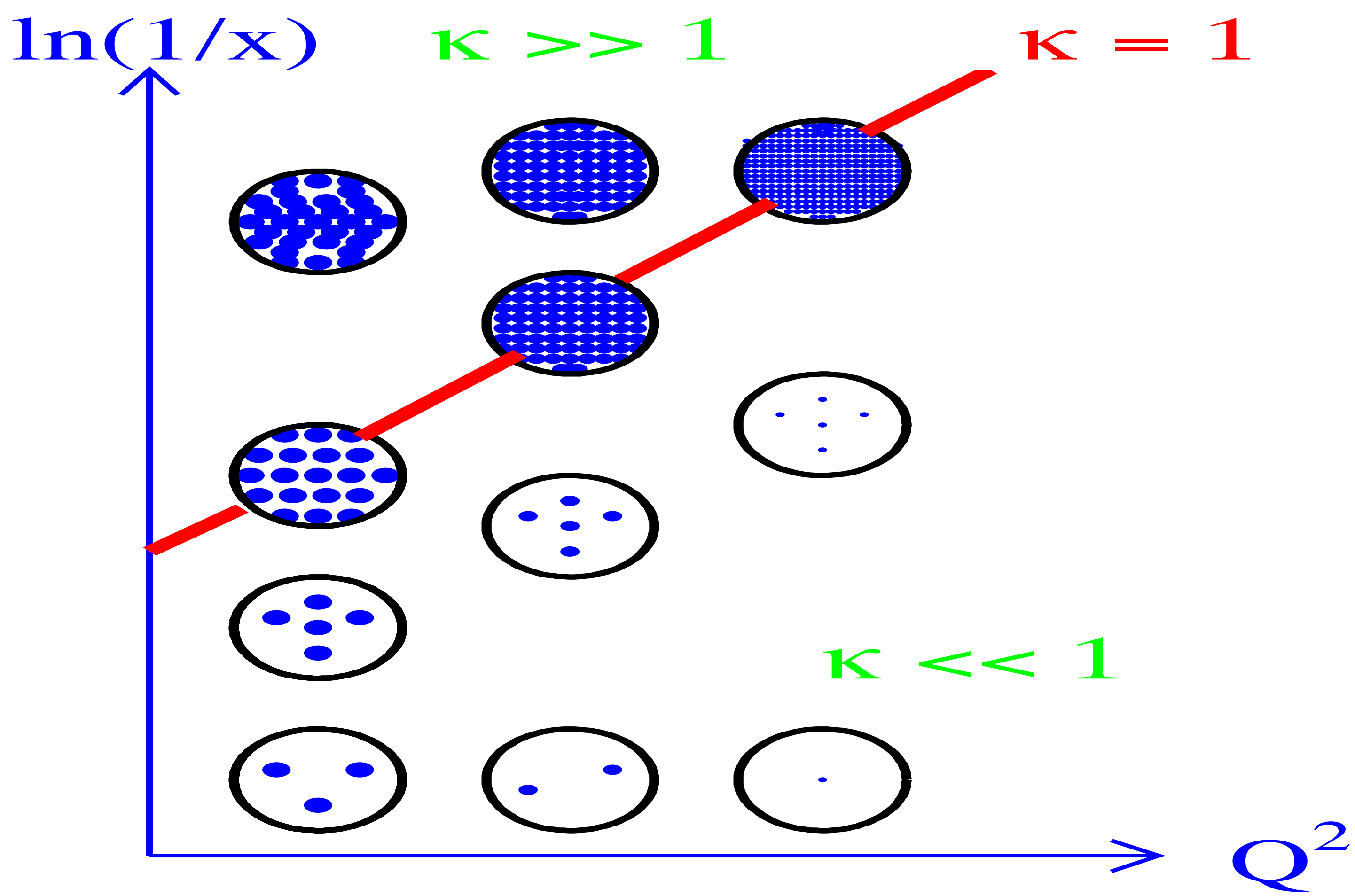
Solution to the classical Yang-Mills equations

$$F_{\mu\nu} \sim \frac{Q_s^2}{g} \quad \text{with} \quad Q_s^2 \sim \rho \sim A^{1/3}\, s^{\lambda}$$

Asymptotic freedom: $\alpha_s(Q_s^2) << 1 \Rightarrow$ Perturbation theory is valid!

Factorization theorems are broken at low x and high A, but a new type of universal characteristic of hadron/nucleus wave function emerges: *color multipole*.

GRIBOV-LEVIN-RYSKIN DIAGRAM

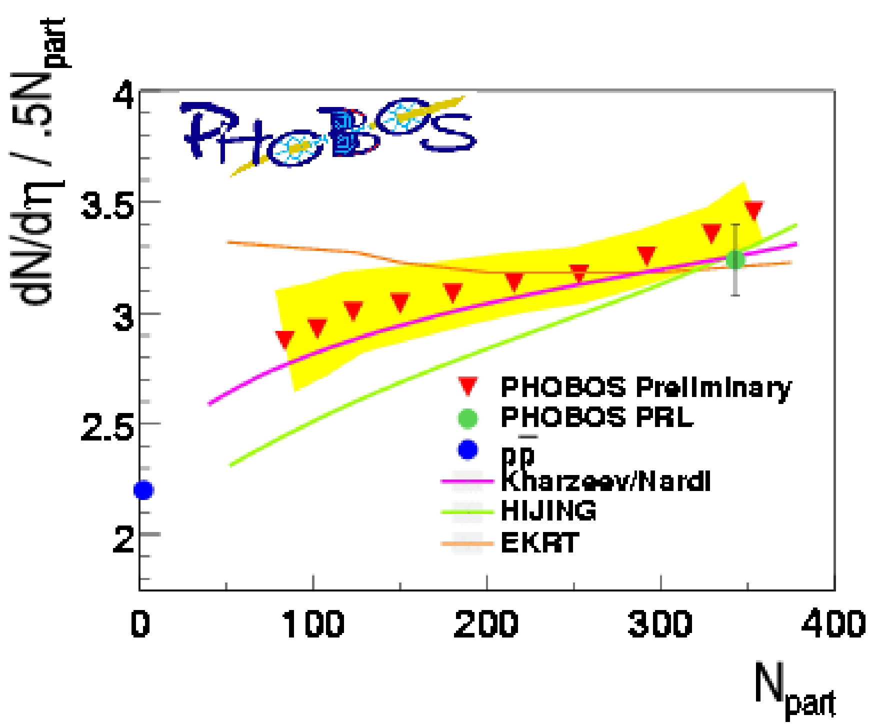


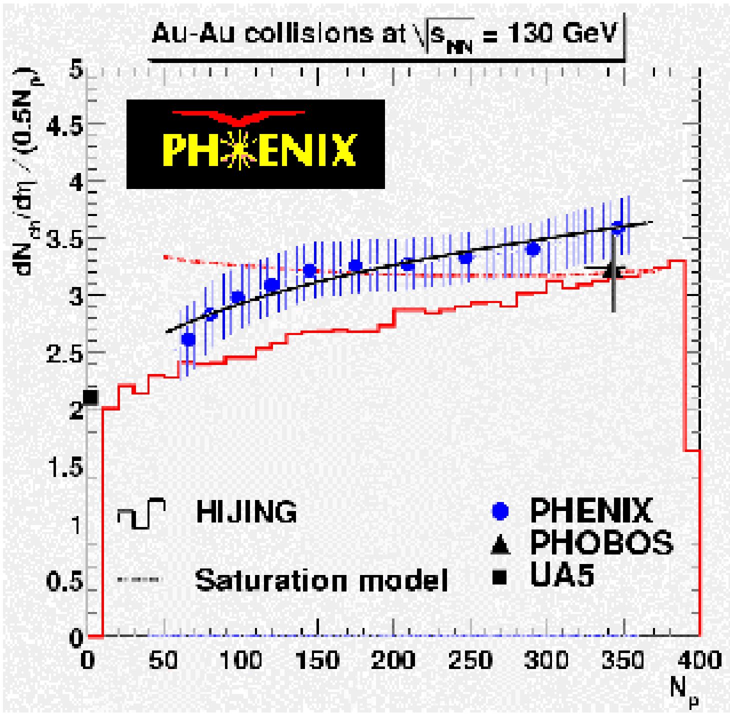
INCLUSIVE LIGHT HADRONS

- Multiplicity is determined only by the initial conditions

KLN model

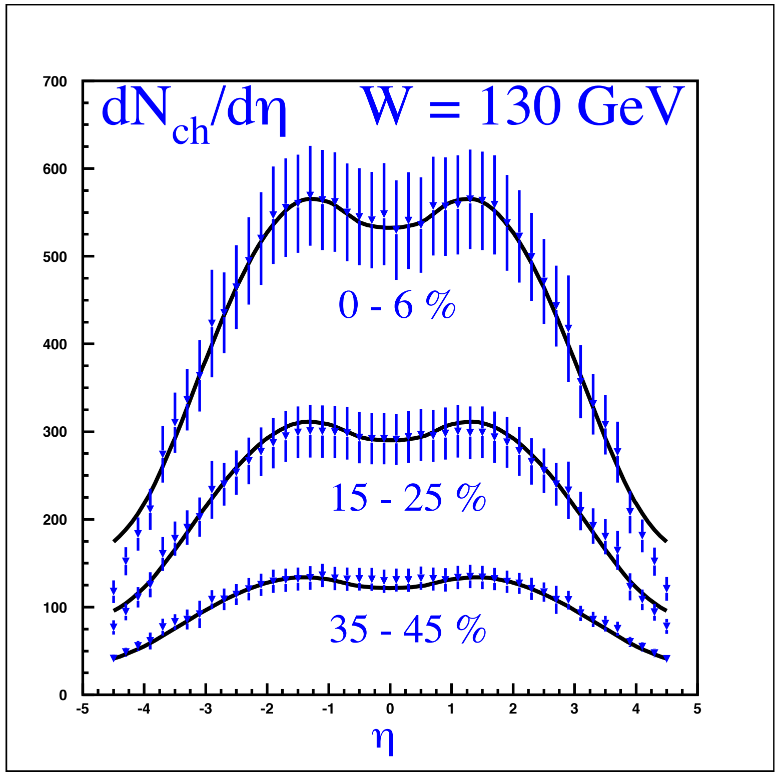
$dN/d\eta$ vs Centrality at $\eta=0$

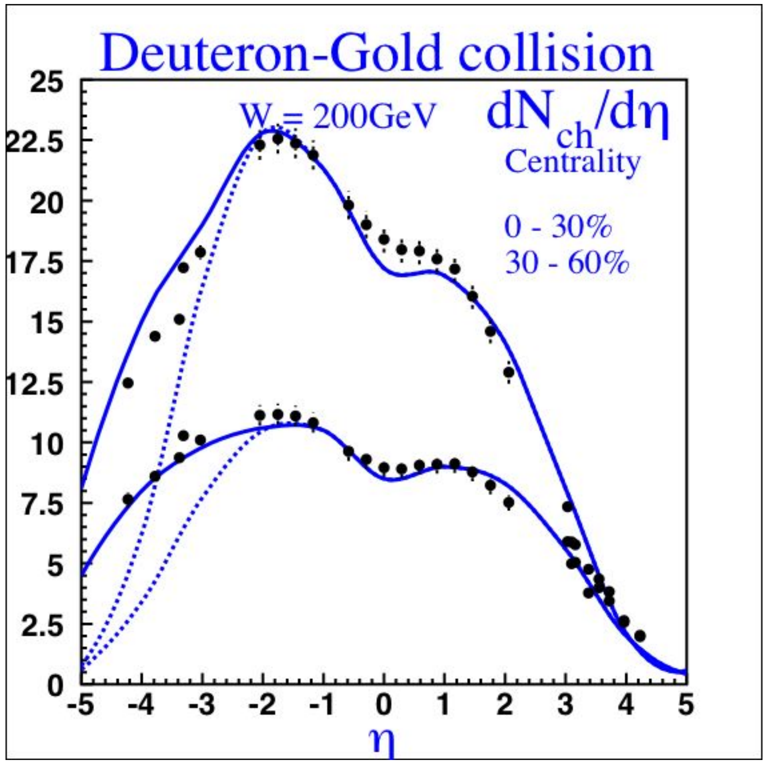


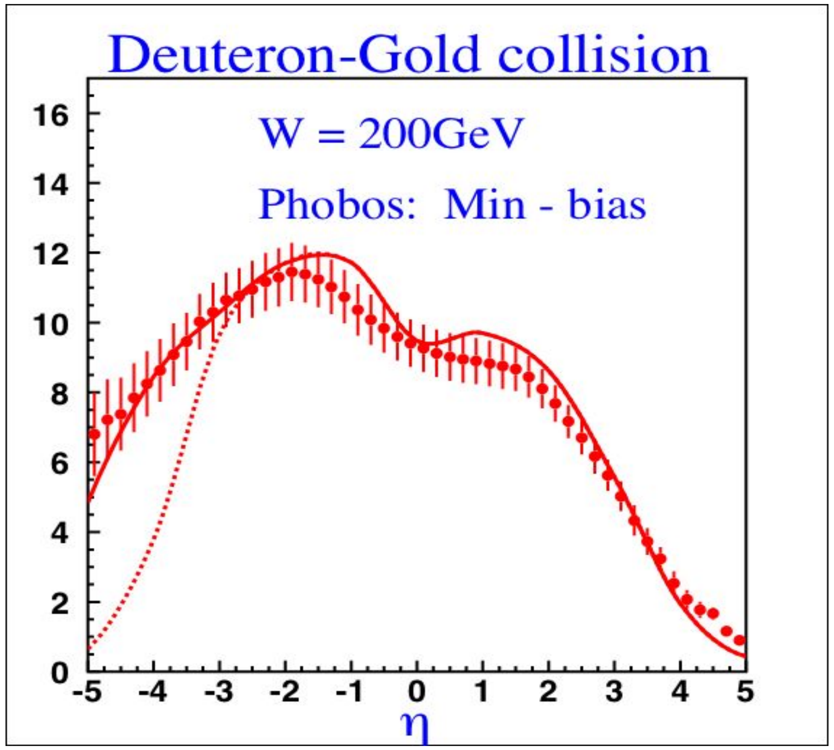


HADRON MULTIPLICITY

Kharzeev, Levin, Nardi

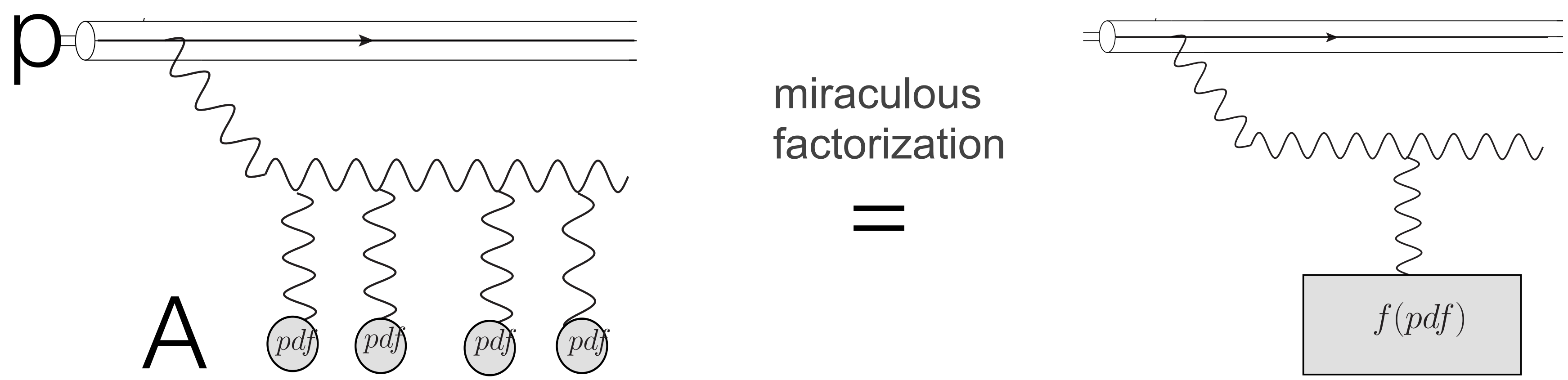




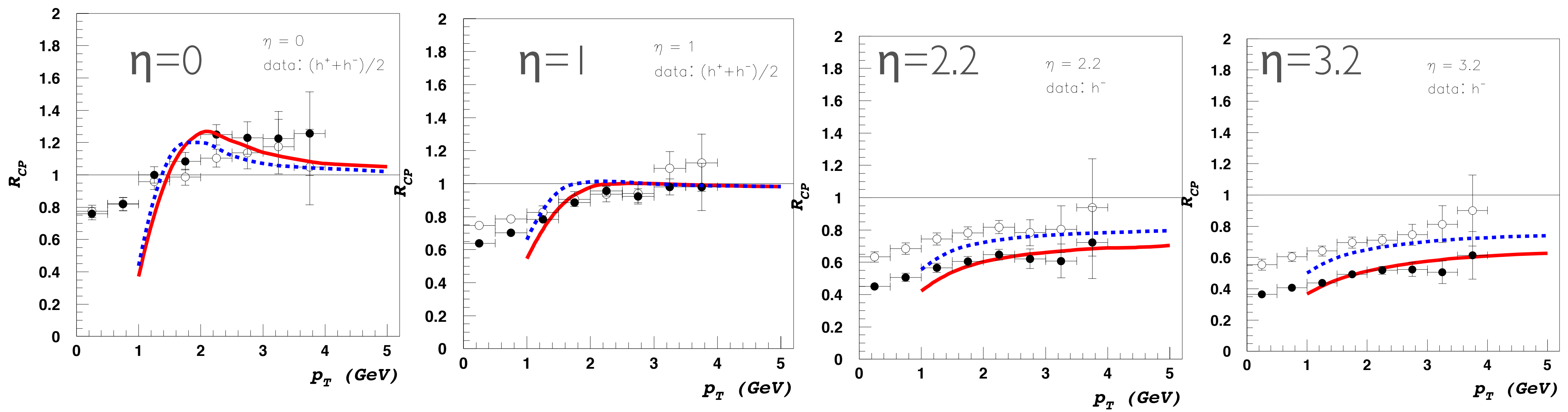


LIGHT HADRON SPECTRA

Kovchegov, KT, 2001

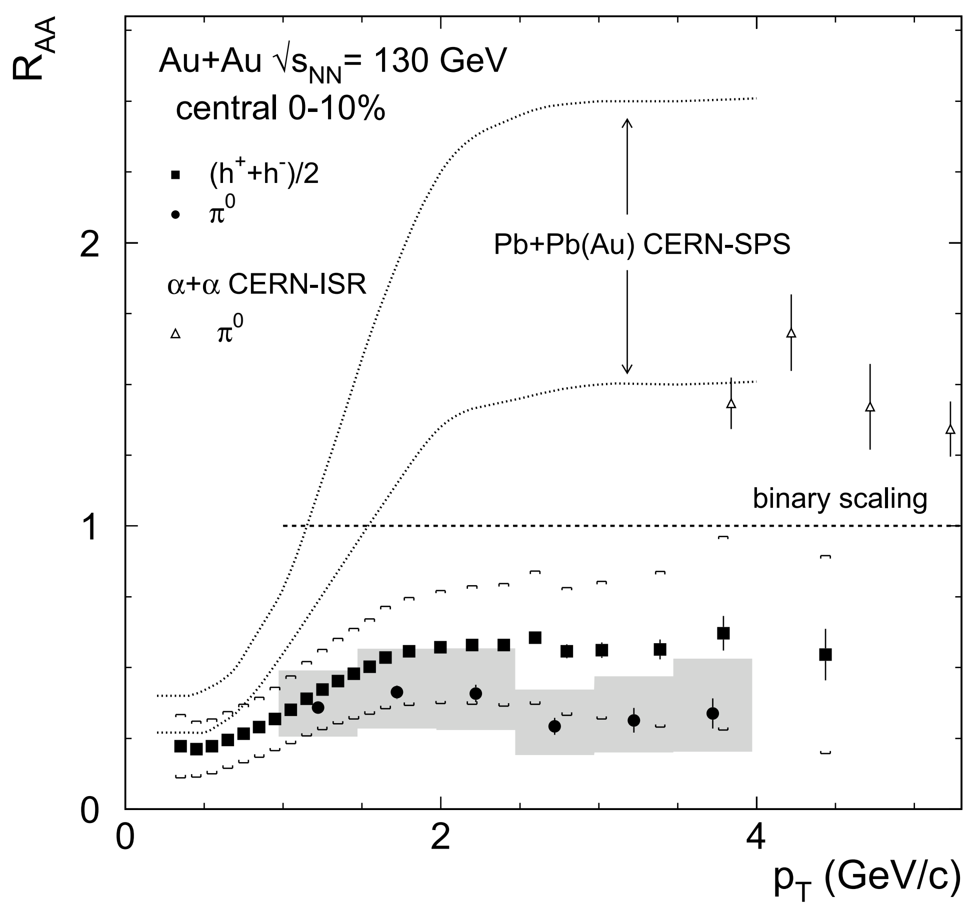


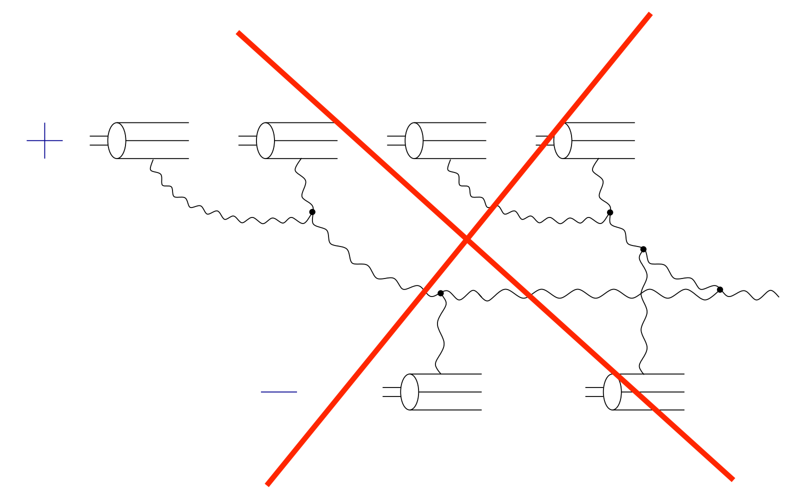
Kharzeev, Kovchegov, KT, 2005



FROM PA TO AA

- Factorization holds for inclusive gluon production in pA (this is the only known case). However, there are no analytical results for AA → need models or numerical calculations → uncertainties.





If there is a factorization we can infer the magnitude of the cold nuclear matter effect in AA from that in DA

EFFECT OF FRAGMENTATION?

- Fragmentation depends only on x_p
- Saturation effect depends only on x_A

$\Rightarrow$

can be tasted by measurements at different $\sqrt{s}$.

Kopeliovich at al

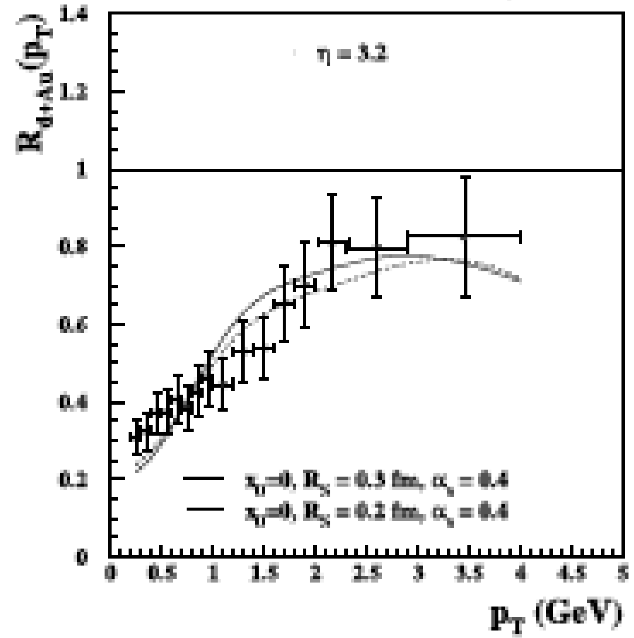
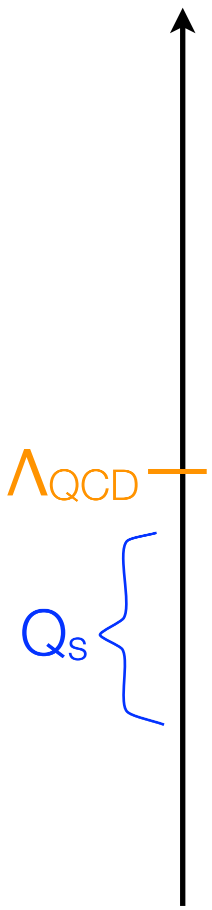


FIG. 3: Ratio of negative particles production rates in $d-Au$ and pp collisions as function of p_T. Data are from [1], solid and dashed curves correspond to calculations with the diquark size 0.3 fm and 0.4 fm respectively.

HEAVY QUARKS



Flavor	Mass
u	$1.5 - 4.5$ MeV
d	$5.0 - 8.5$ MeV
s	$80 - 155$ MeV
c	$1.0 - 1.4$ GeV
b	$4.0 - 4.5$ GeV
t	174.3 ± 5.1 GeV

Light quarks

Heavy quarks

`Heavy' and `light' are determined by the ratio m^2/Q_s^2

- Heavy quarks are produced at short distances ~1/2m~0.1 fm (charm) ⇒ α_s<<1

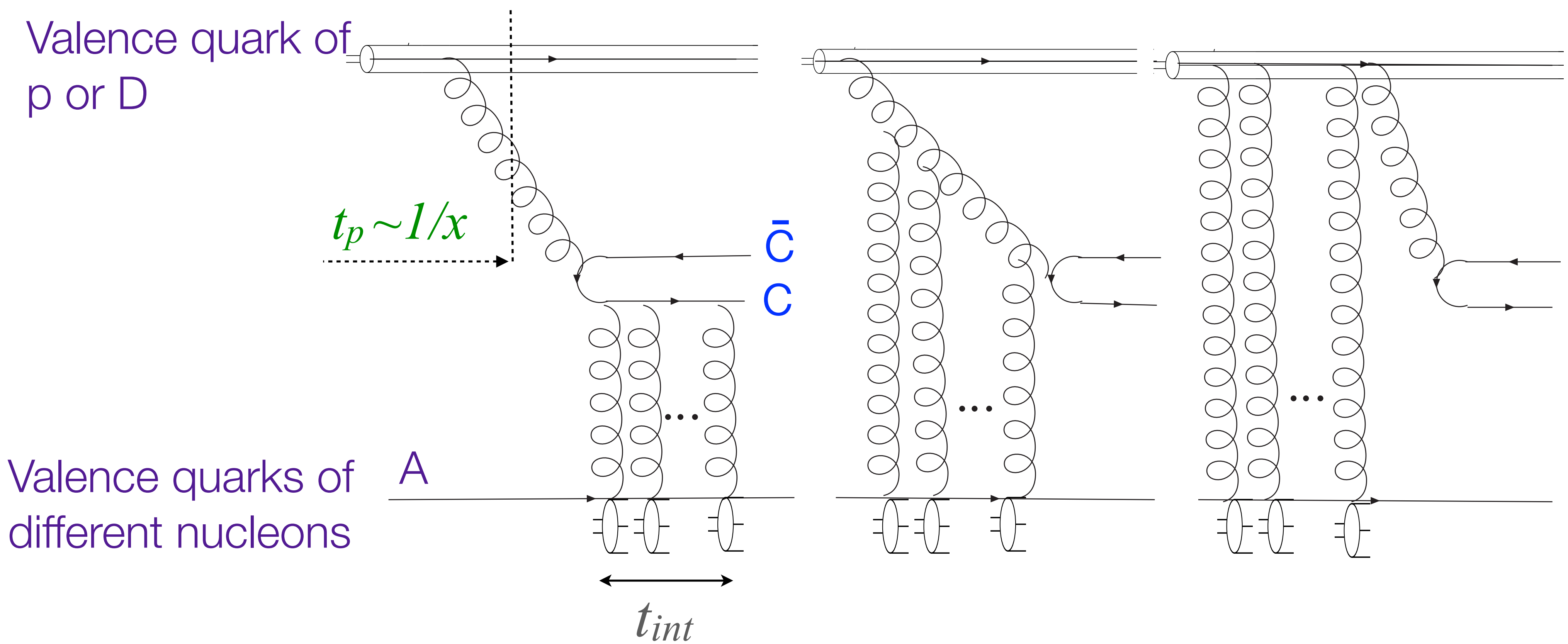
- However, quarkonium binding is not perturbative:

$$\frac{M^2 - 4m^2}{4m^2} \ll 1$$

Therefore, cc→J/ψ is non-perturbative

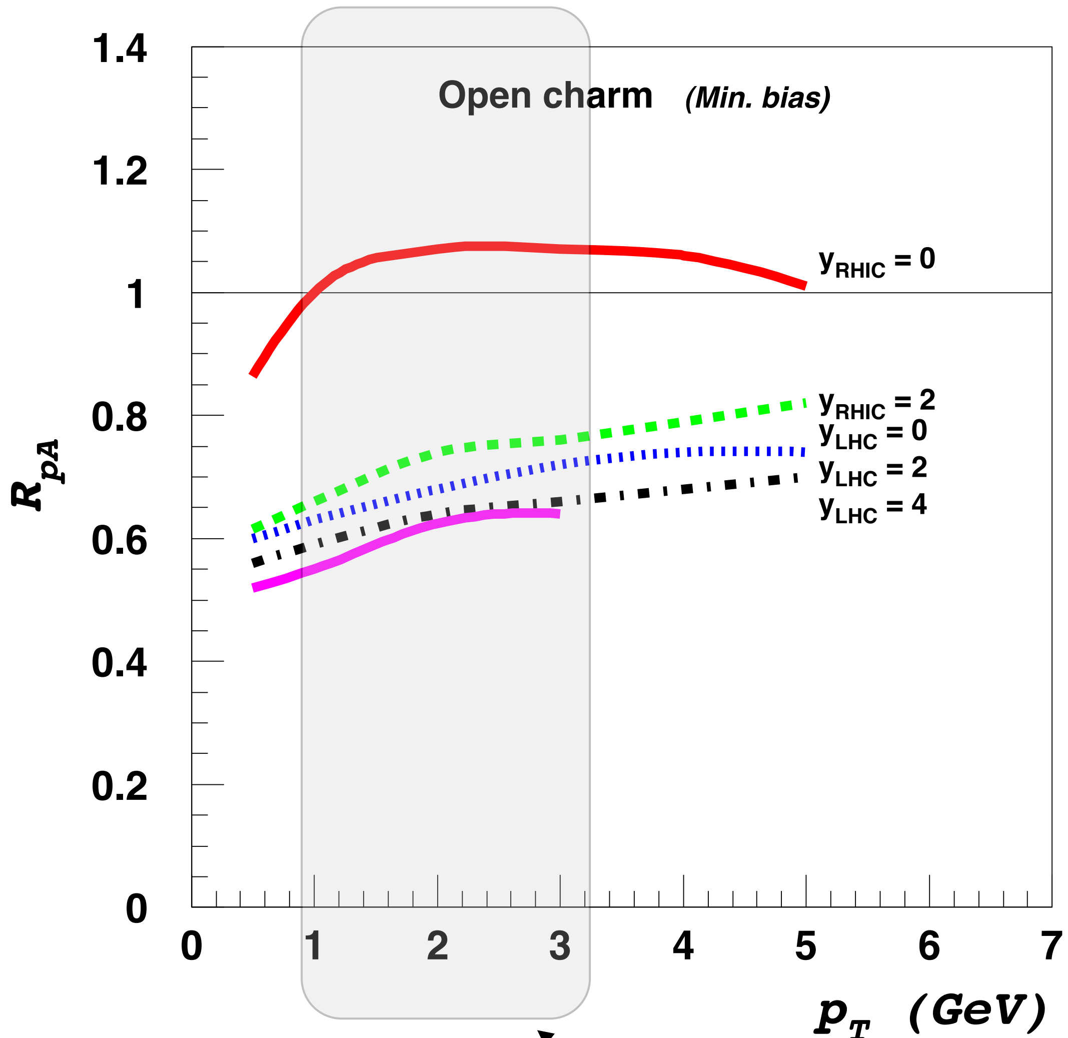
INCLUSIVE OPEN HEAVY QUARK

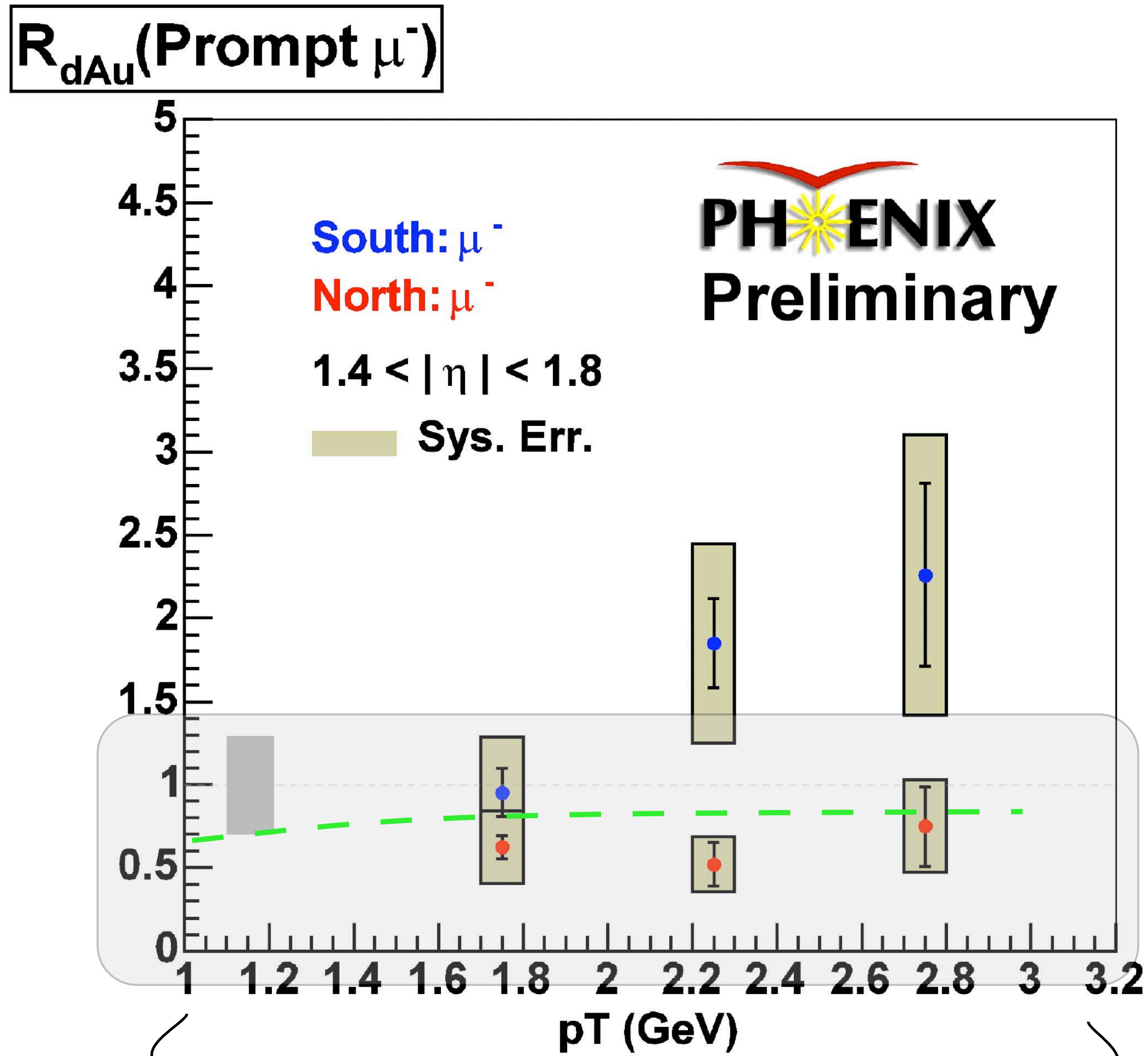
Kopeliovich et al , 2001
KT 2004;
Blaizot, Gelis,
Venugopalan 2004;
Kovchegov, KT 2006



INCLUSIVE OPEN CHARM

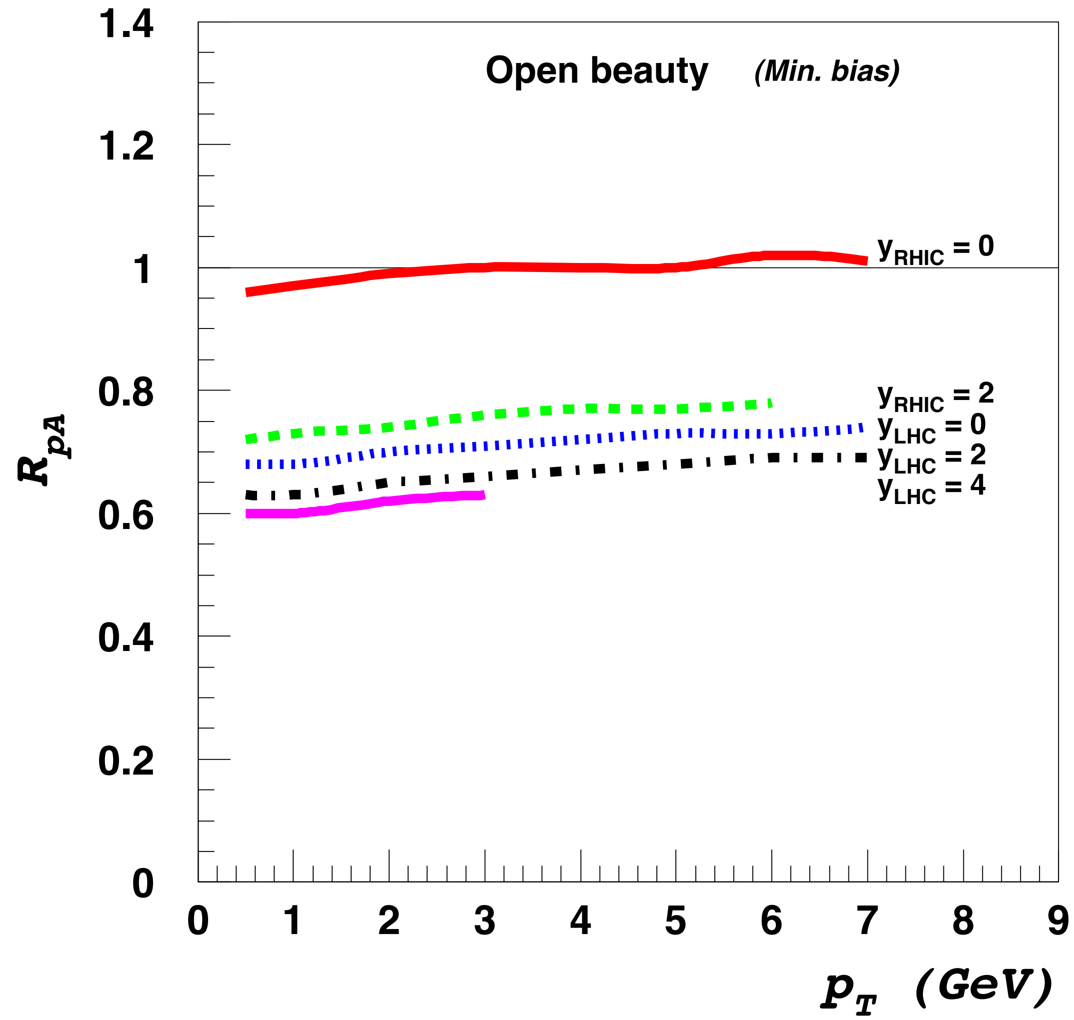
KT, 2004, 2007

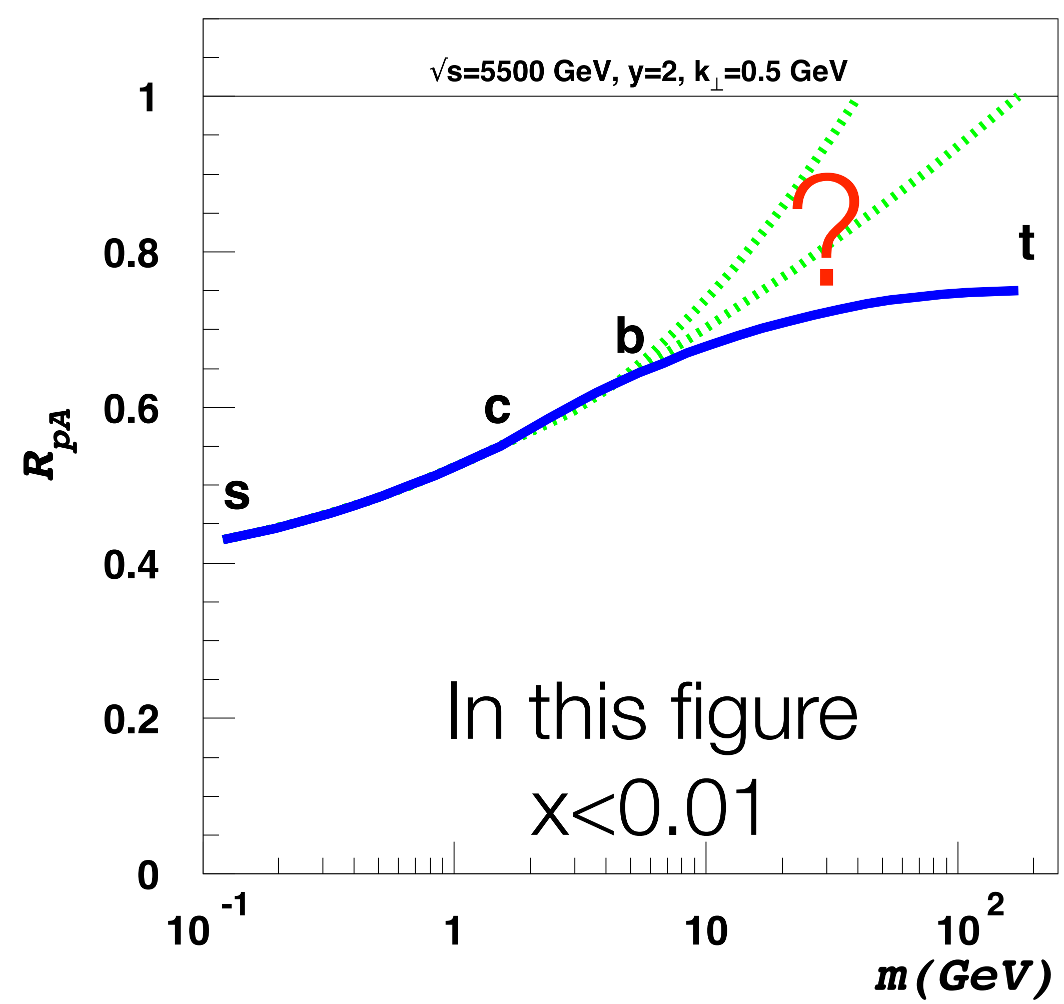




INCLUSIVE OPEN BEAUTY

KKT model
KT, 2007

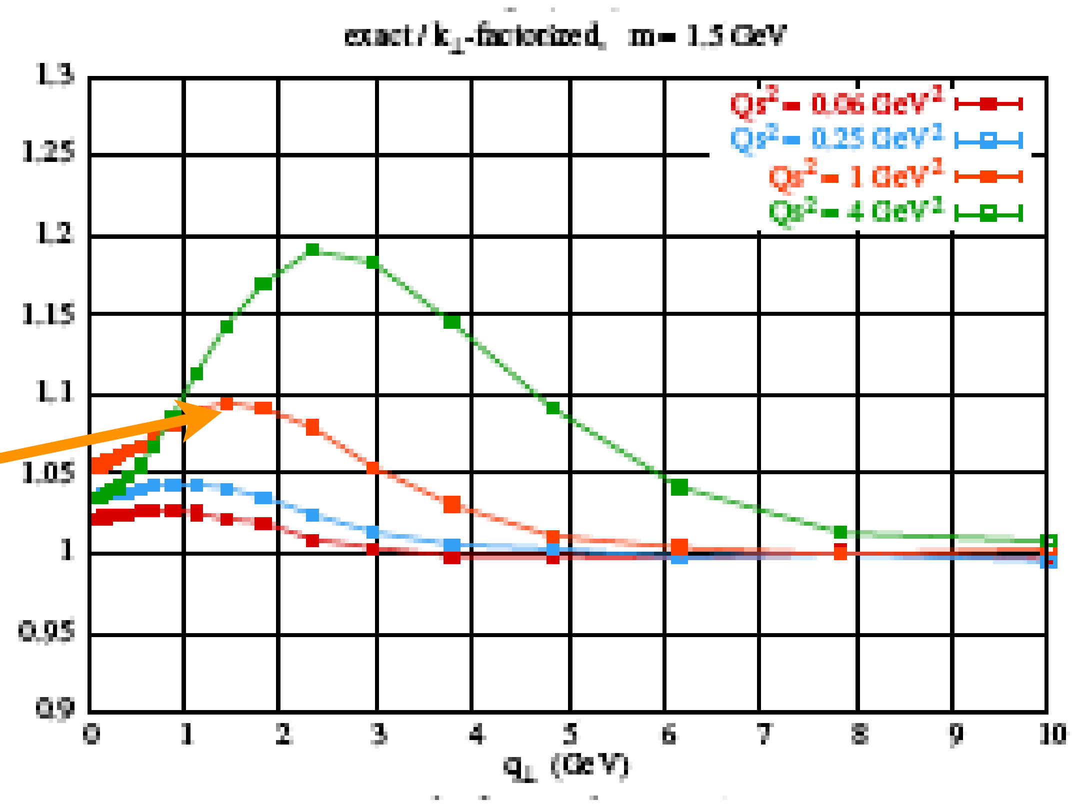




Need higher p_T measurements to understand the transition to hard pQCD

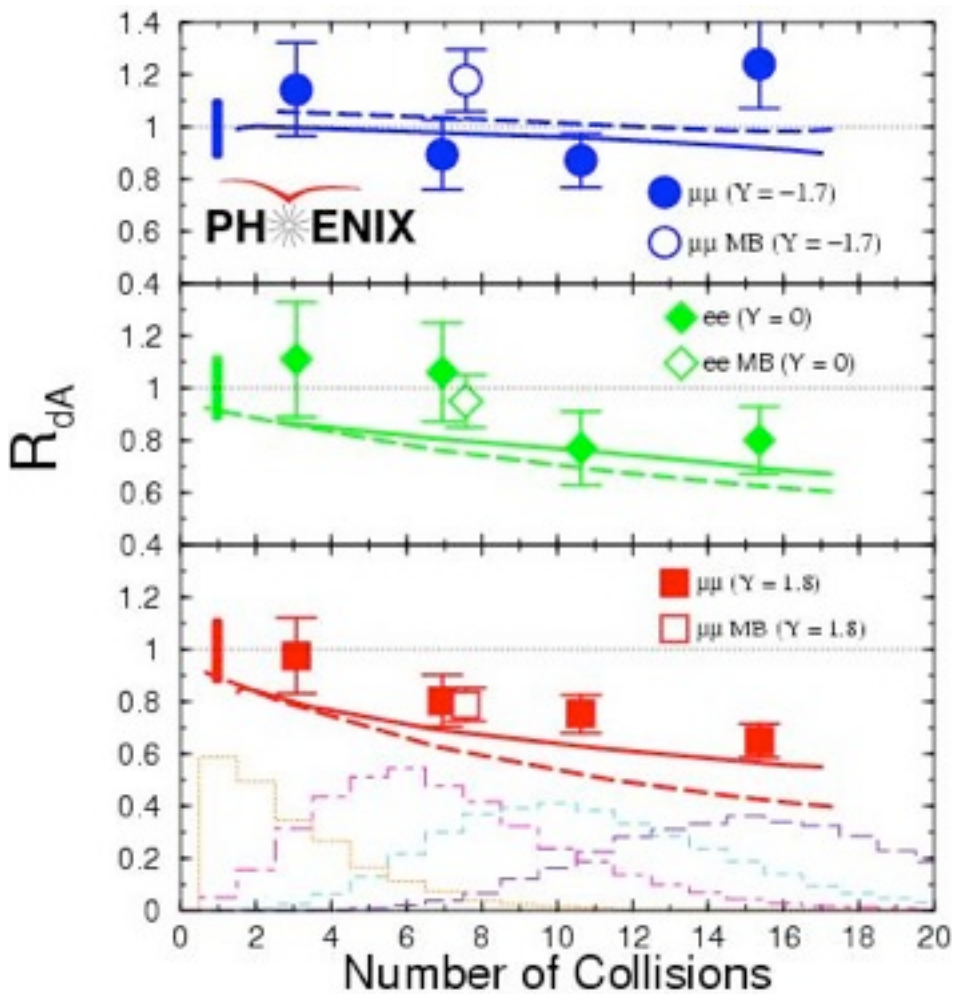
FACTORIZATION IN OPEN CHARM

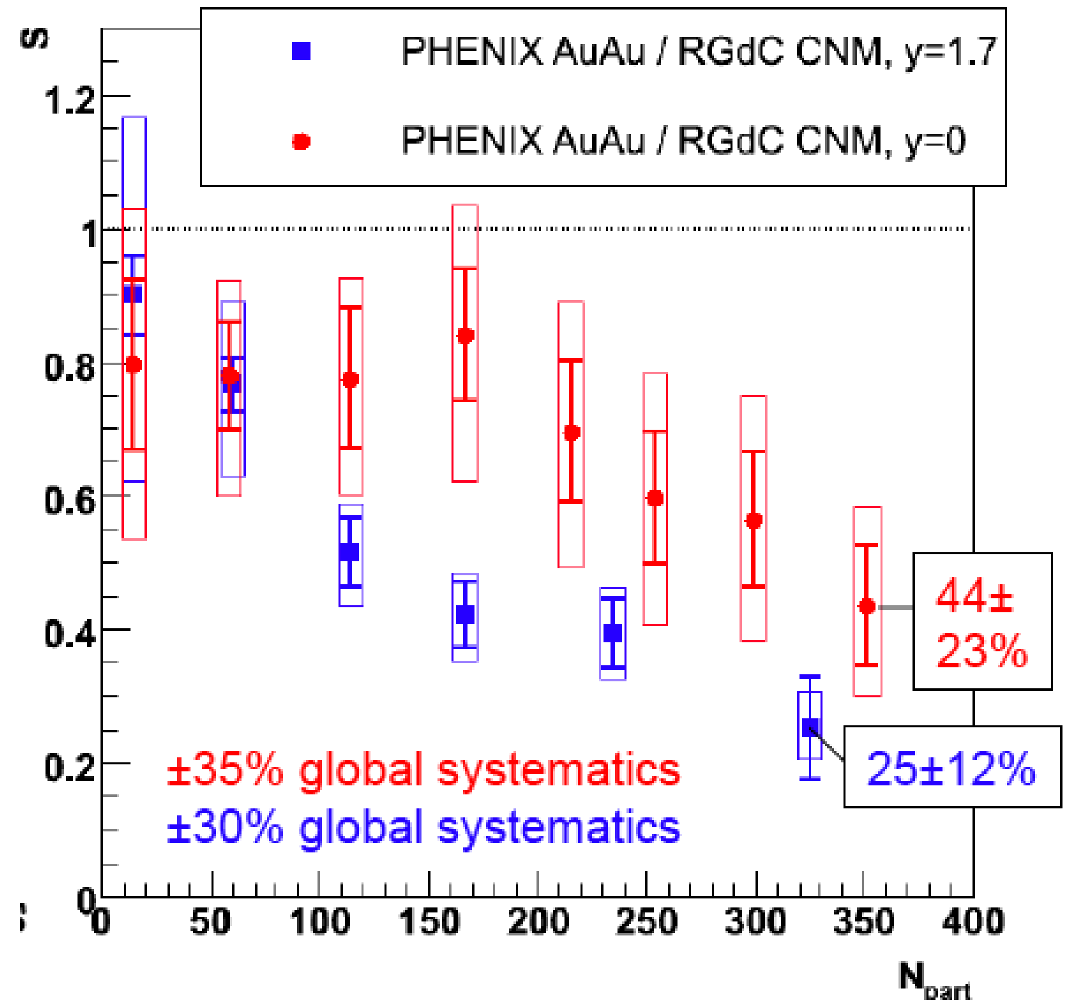
RHIC



Fujii, Gelis, Venugopalan

FACTORIZATION IN J/Ψ





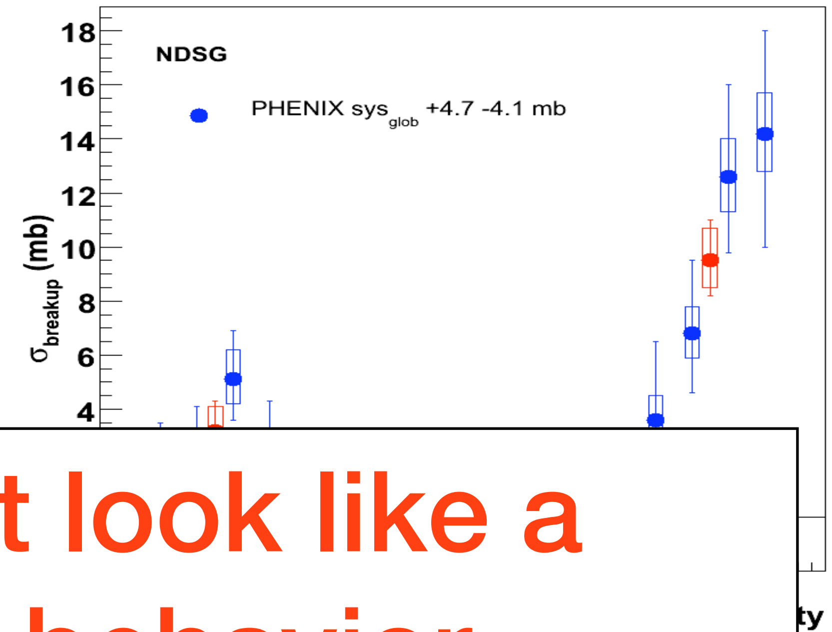
We cannot infer the the cold nuclear matter effect in AA from DA.

ASSUMING FACTORIZATION IN J/Ψ

The effective absorption cross sections from fits of Ramona's calculations [3] to PHENIX d+Au R_{CP} data are shown for each shadowing model.

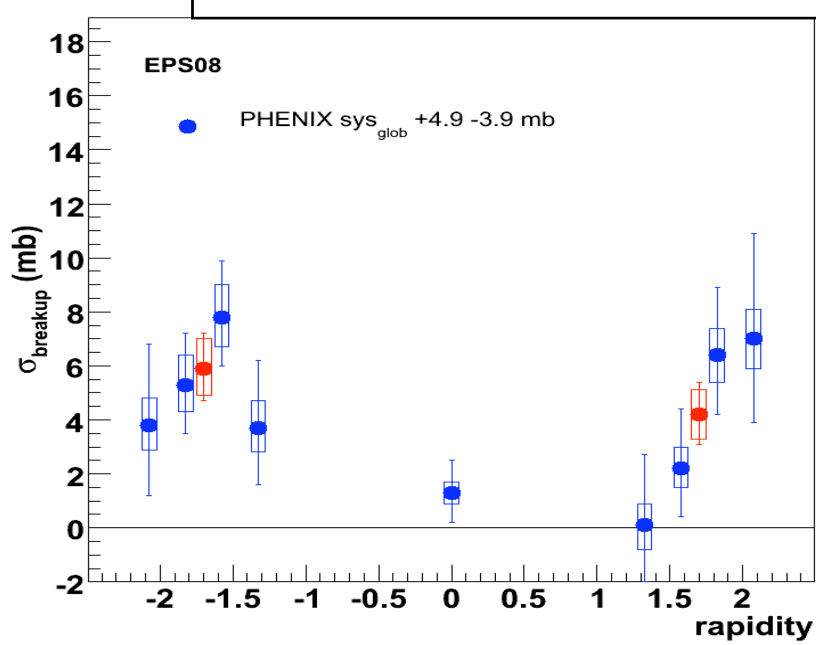
This is **not** an attempt to extract physics from the d+Au R_{CP}! This is just a parameterization of the data that is independent at each rapidity.

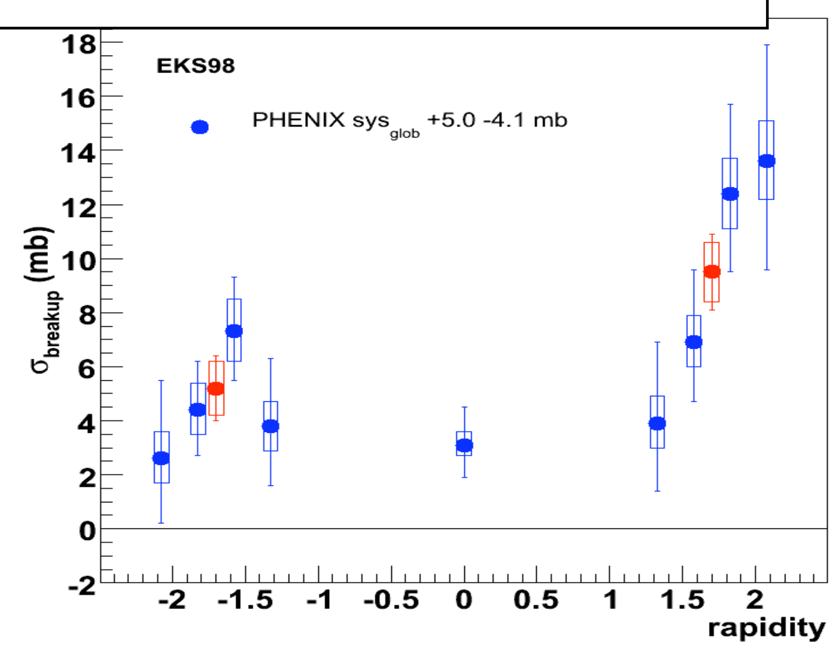
The red p
y = -1.7 a



Slide stolen from T. Frawley

This does not look like a reasonable behavior.

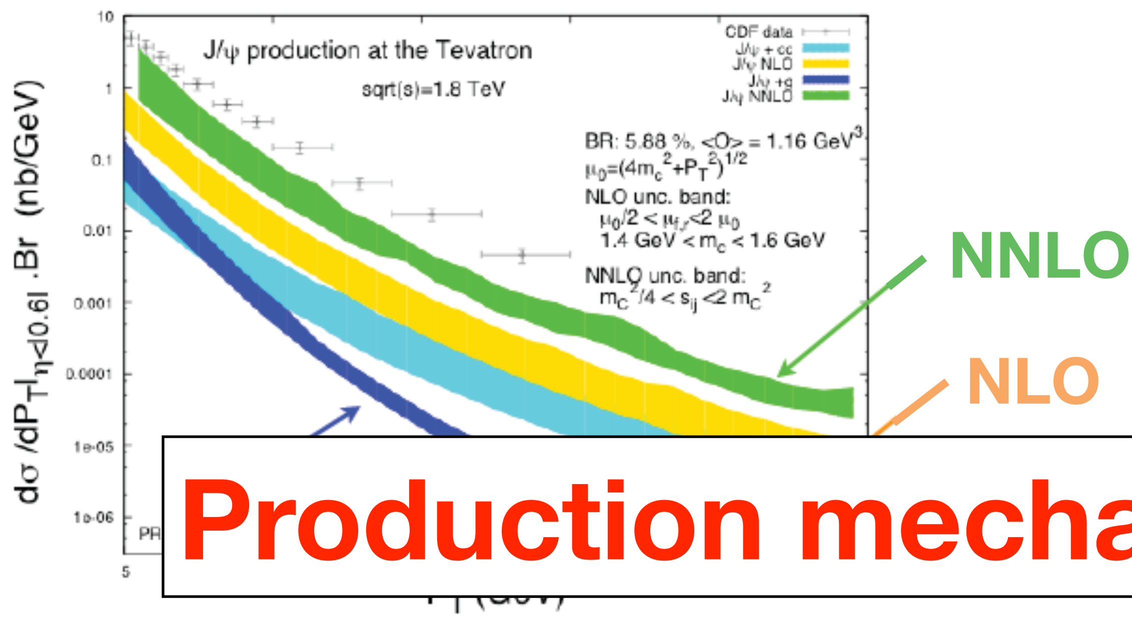




Similar results obtained by Lansberg et al 2010.

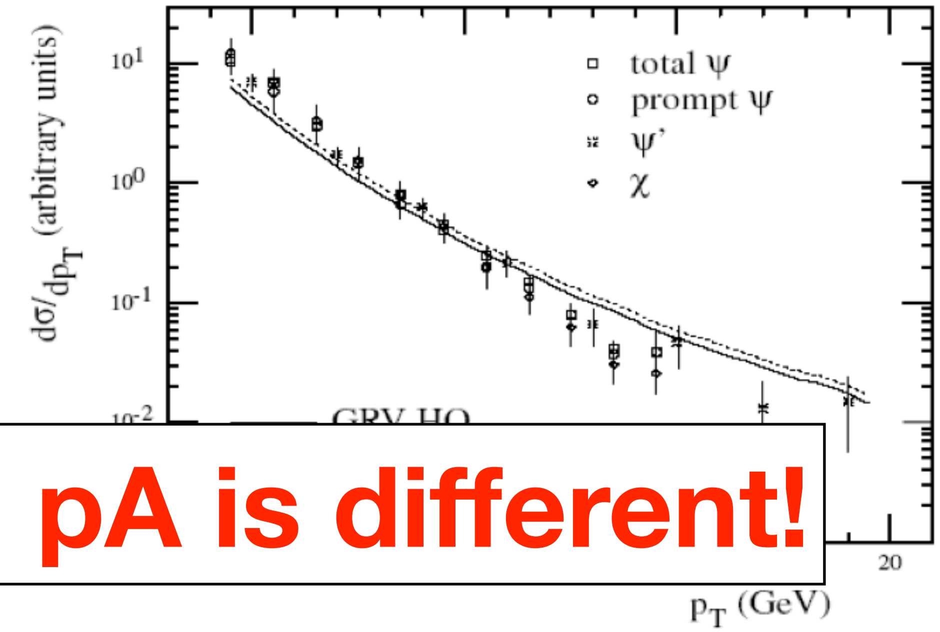
J/Ψ PRODUCTION MECHANISMS

- Color singlet model



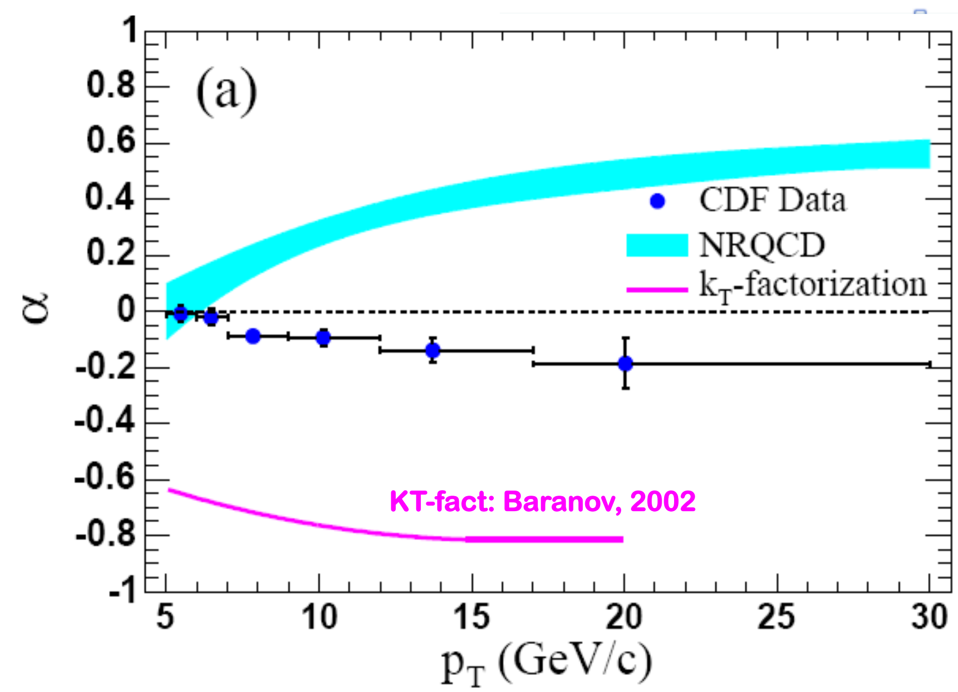
- Color evaporation model

Amundson et al, 1997



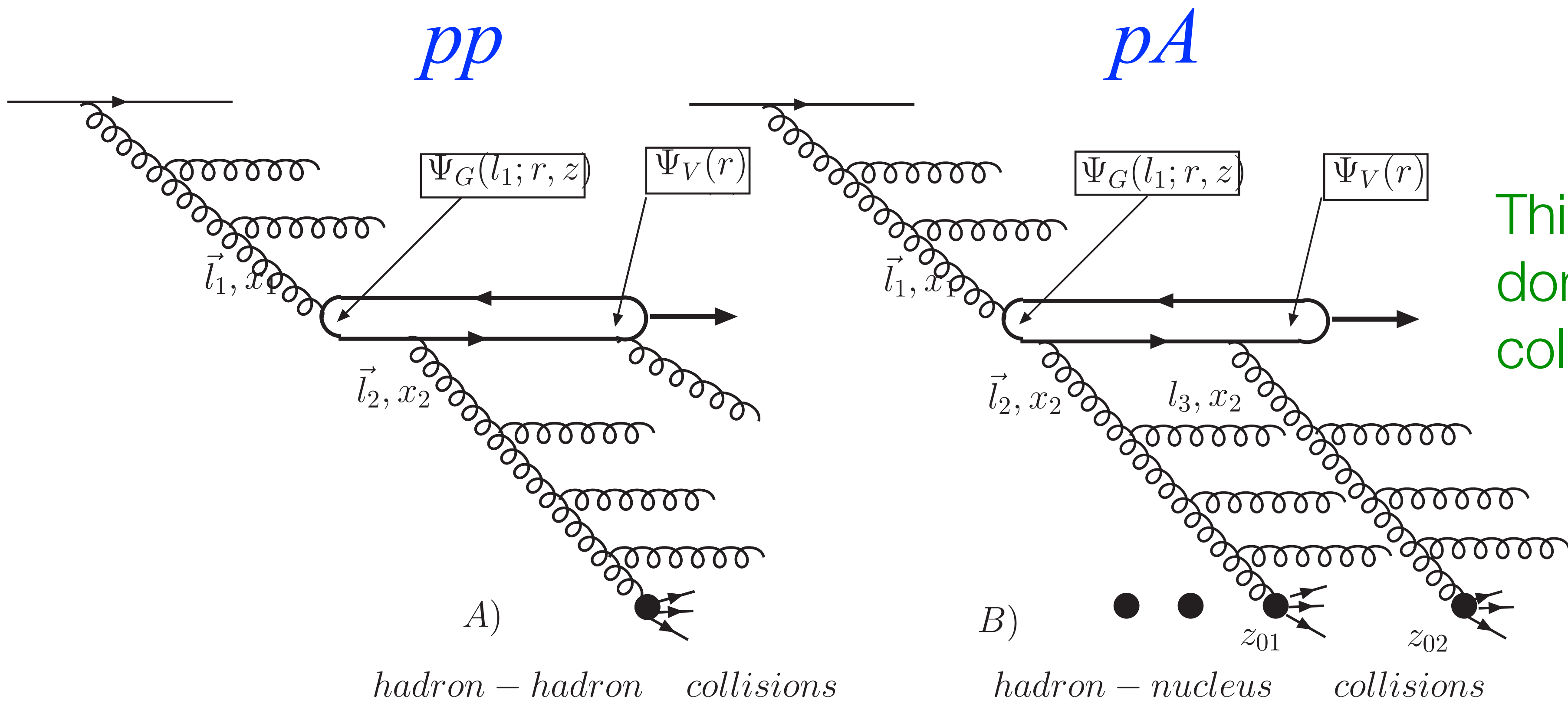
Production mechanism in pA is different!

- Non-relativistic QCD model



J/Ψ PRODUCTION IN PA

Kharzeev, KT,2005
Kharzeev, Levin, Nardi, KT,2009



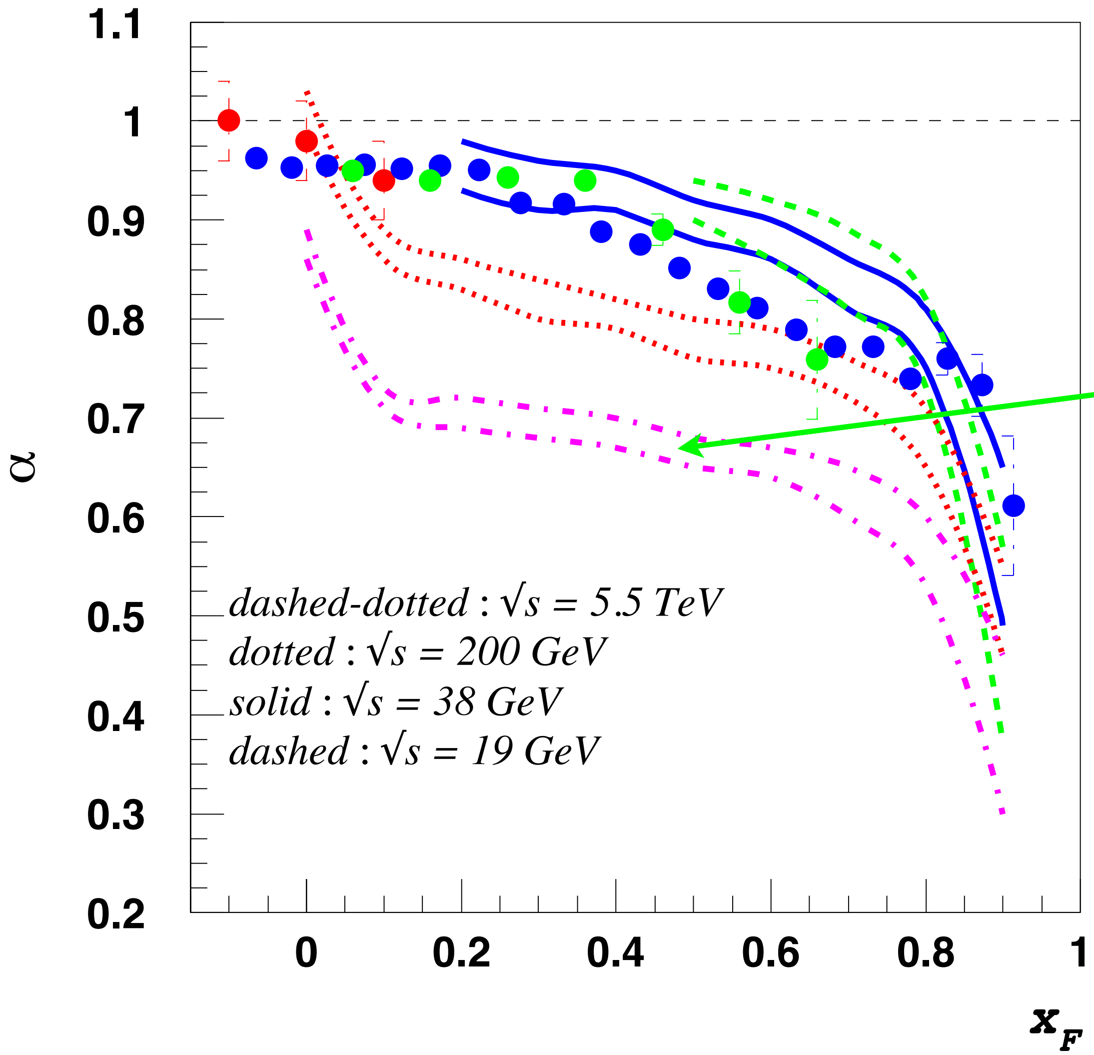
This mechanism is dominant for central collisions.

$$\alpha_s^3 A^{1/3} = \alpha_s(\alpha_s^2 A^{1/3}) \sim \alpha_s \qquad \alpha_s^4 A^{2/3} = (\alpha_s^2 A^{1/3})^2 \sim 1$$

Note that the factorization is broken already at the lowest order.

BREAKDOWN OF X_F SCALING

Kharzeev, KT , 2005



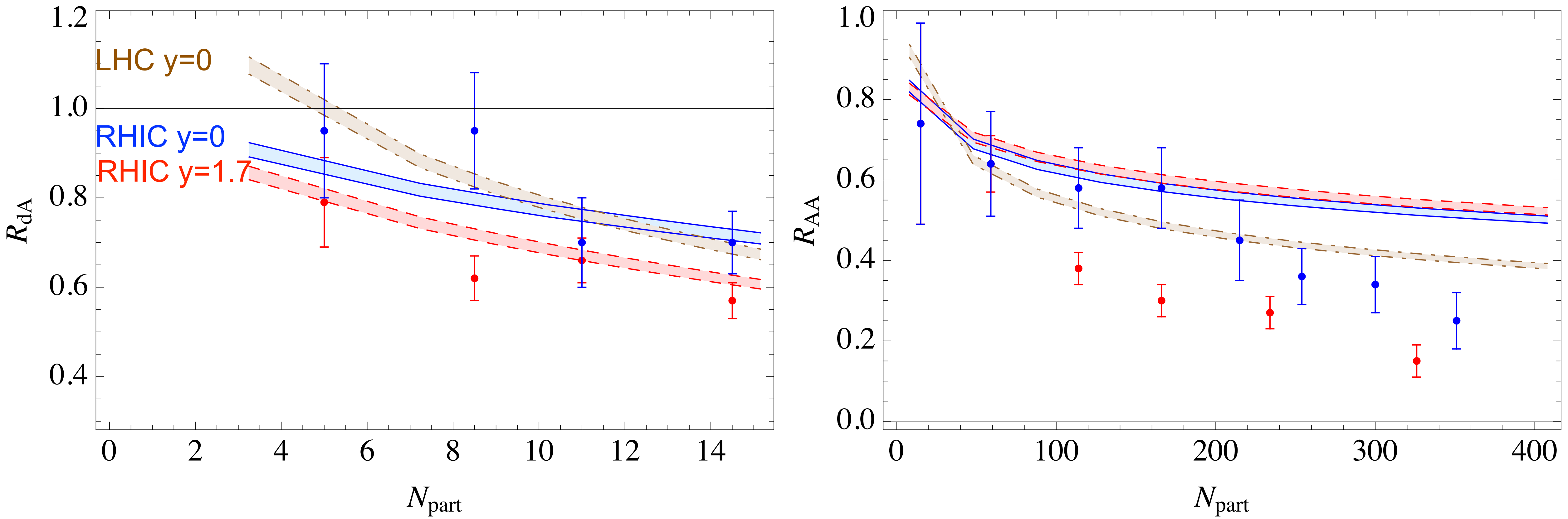
$\sigma_{pA}=A^{\alpha}\sigma_{pp}$

α=2/3 plateau: black disk regime.

Additional assumptions:

- J/ψ is non-relativistic. Relativistic correction depends on m but not on energy - included in prefactor.
- Parametrically small corrections due to the real part and off-diagonal matrix elements are neglected.

J/Ψ PRODUCTION IN DA AND AA



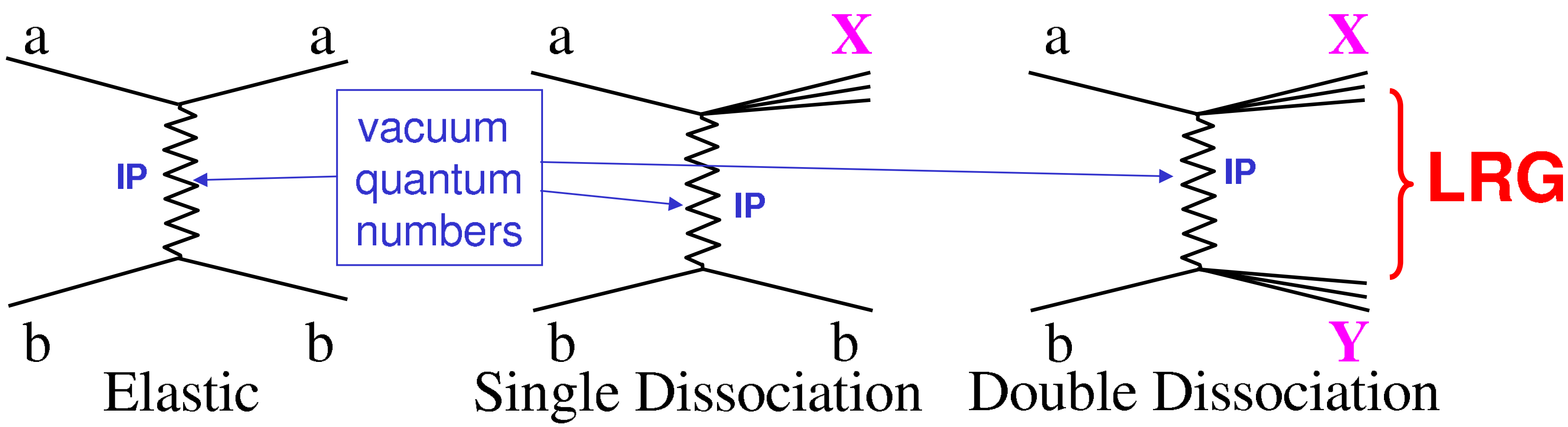
Anomalous suppression in AA is probably due to hot medium effects.

- Polarization of J/ψ -?
- Production of χ_c, ψ' -?
- Compare with DY.

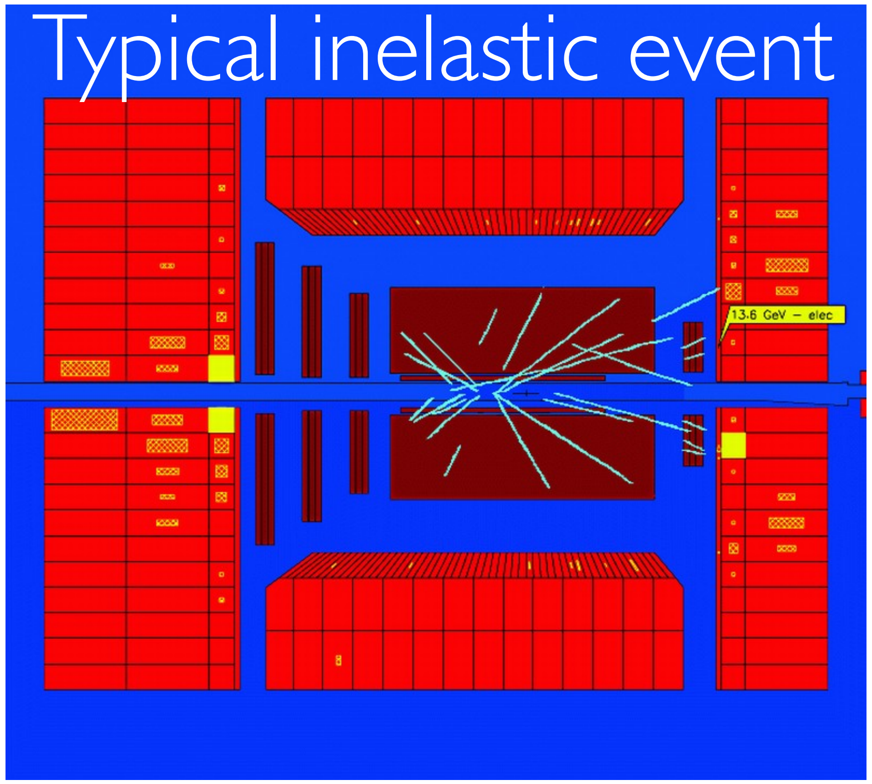
Need these measurements in dA!

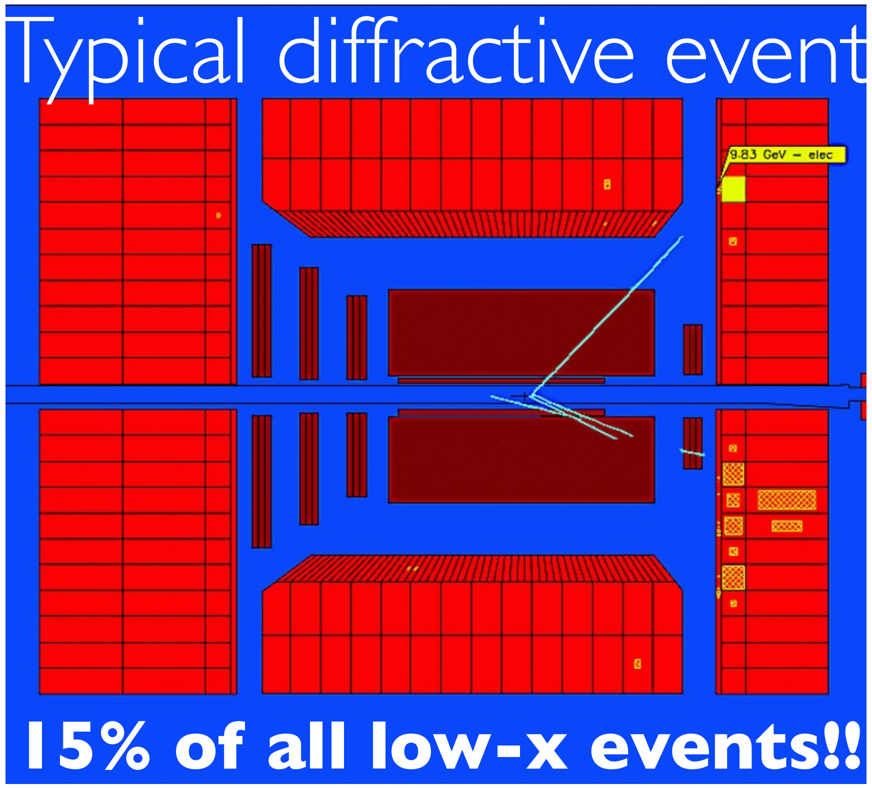
It may shed light on J/ψ production in pp ...

DIFFRACTION



DIS:

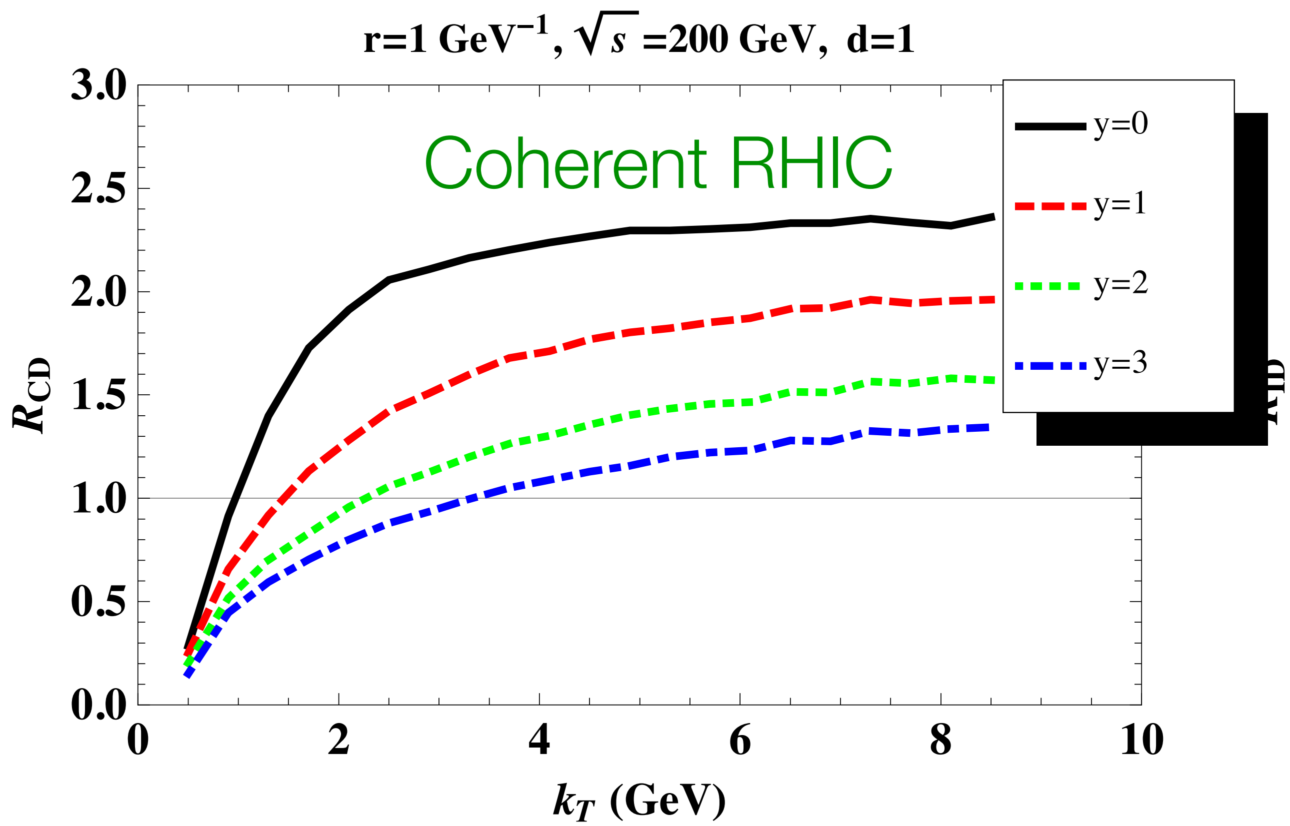


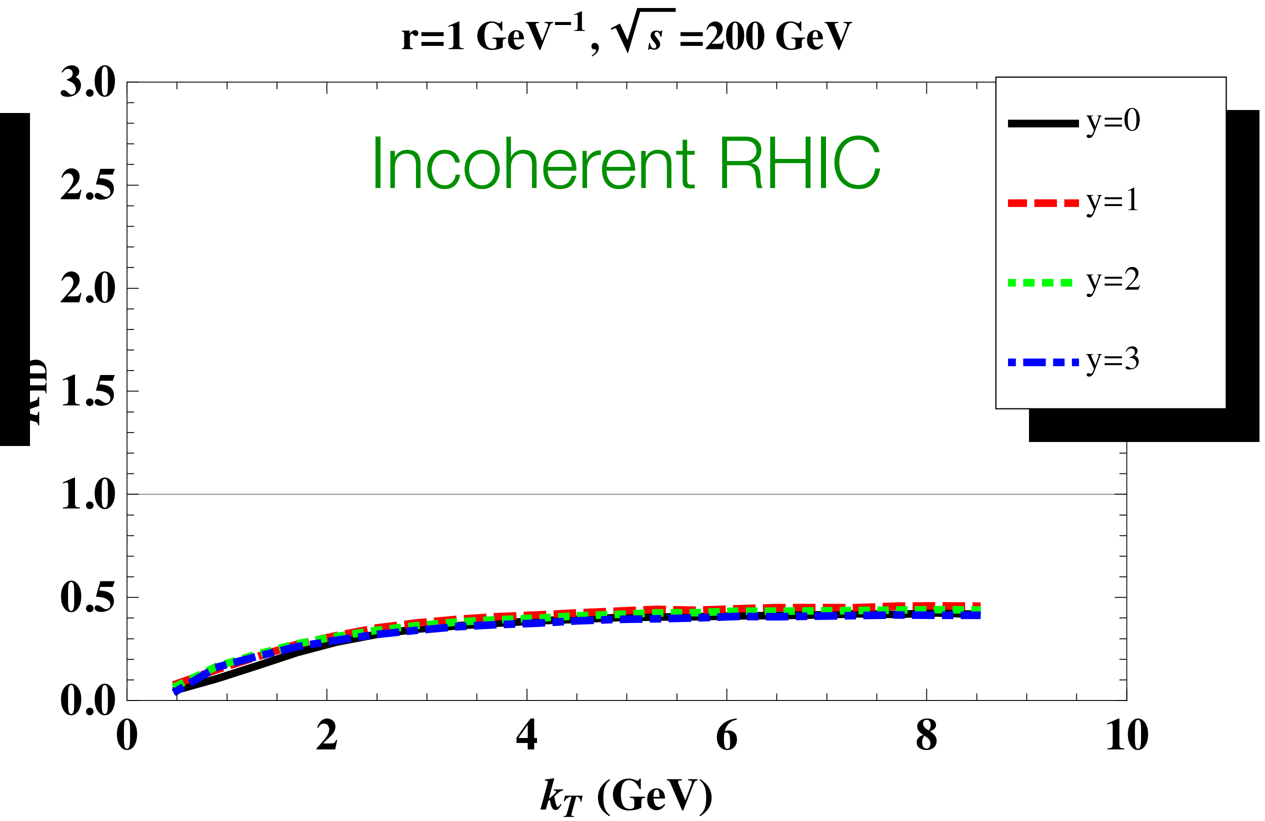


Diffraction measures quantum fluctuations of the CGC fields

DIFFRACTION IN PA

KT, 2008





Similar to inclusive hadrons, but much stronger rapidity dependence ⇒ more sensitive to low x.

AZIMUTHAL CORRELATIONS IN PA

KT, 2010

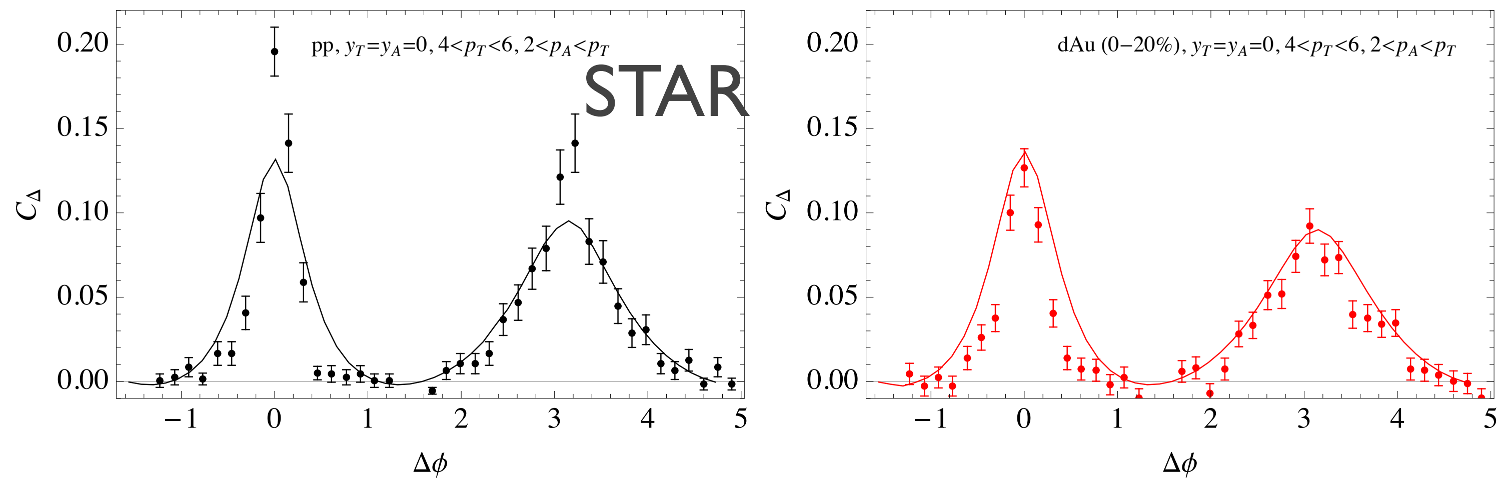
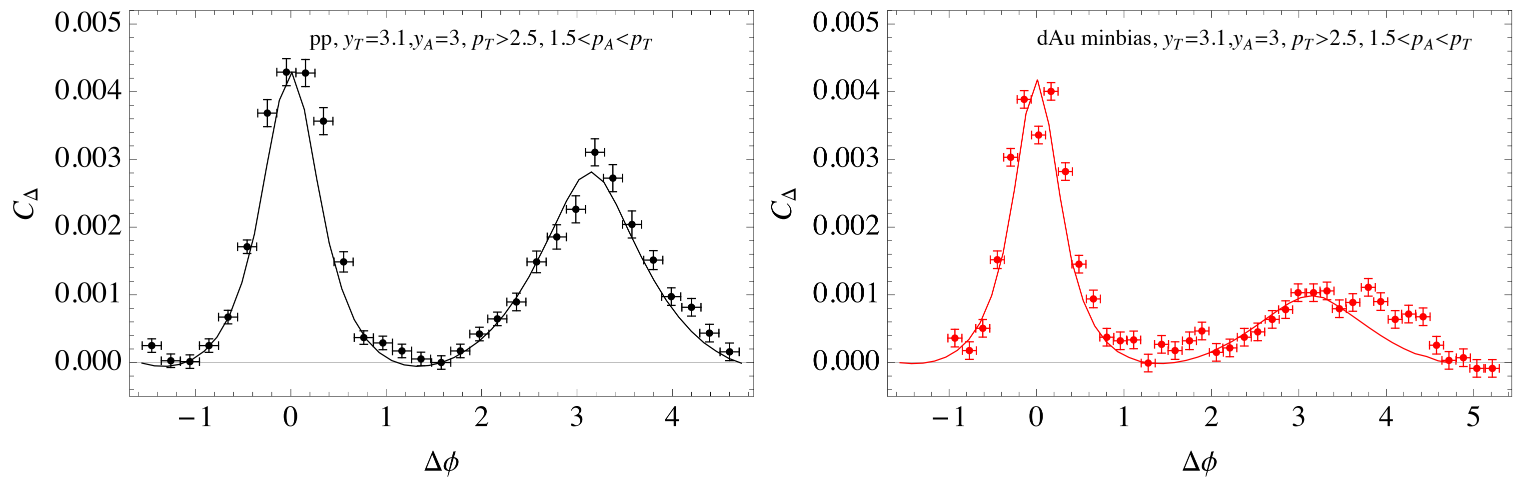


FIG. 1: Correlation function at the central rapidity. Kinematic region is $4 < p_T < 6$, $2 < p_A < p_T$ (all momenta are in GeV), $y_T = 3.1$, $y_A = 3$. Left (right) panel: minbias pp (dAu) collisions. Data from [48].



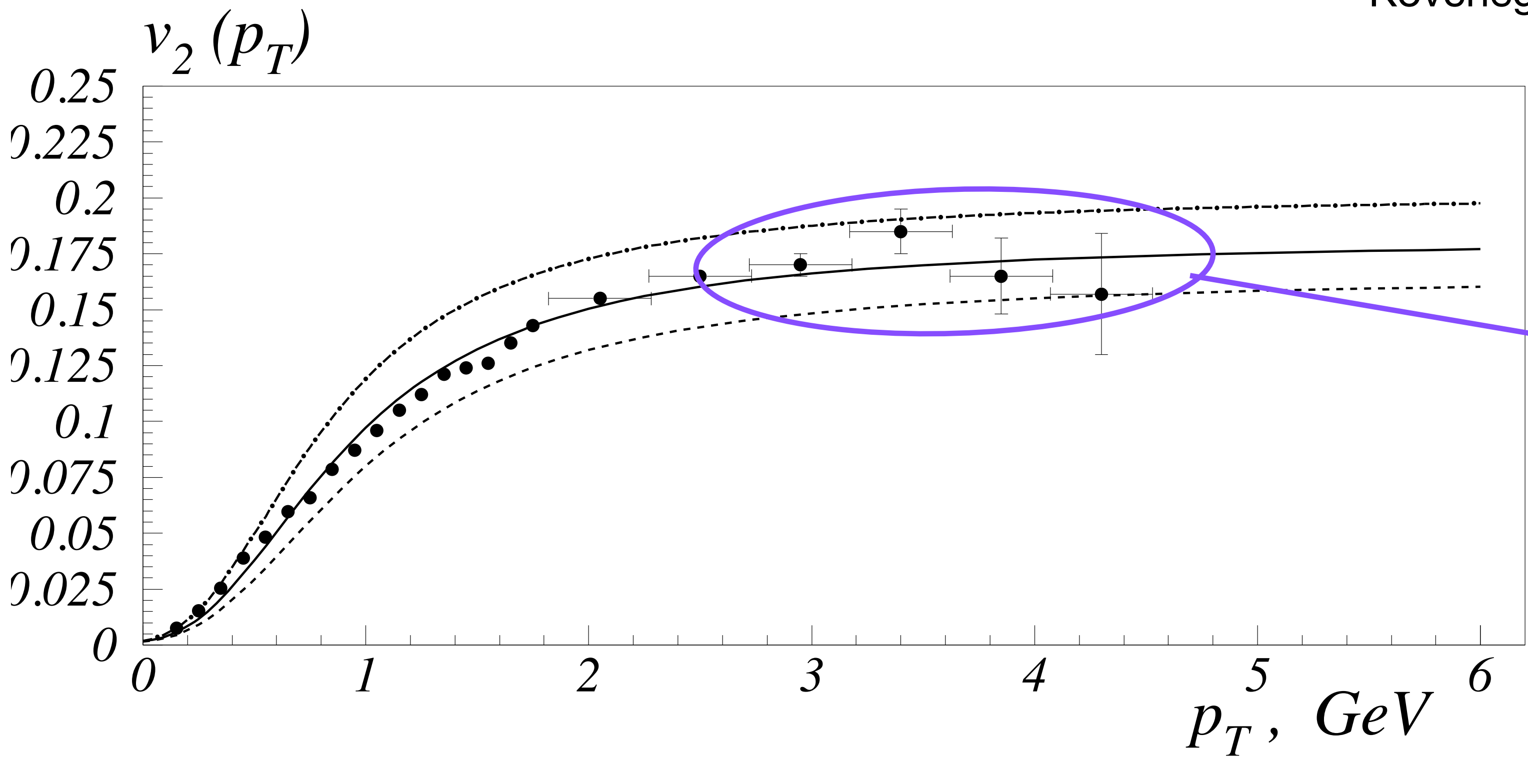
Need higher p_T

FIG. 2: Correlation function at forward rapidities. Kinematic region is $p_T > 4$, $1.5 < p_A < p_T$ (all momenta are in GeV), $y_T = 3.1$, $y_A = 3$. Left (right) panel: the minbias pp (dAu) collisions. Data from [49].

- Azimuthal correlations in pA:→ calibration of AA

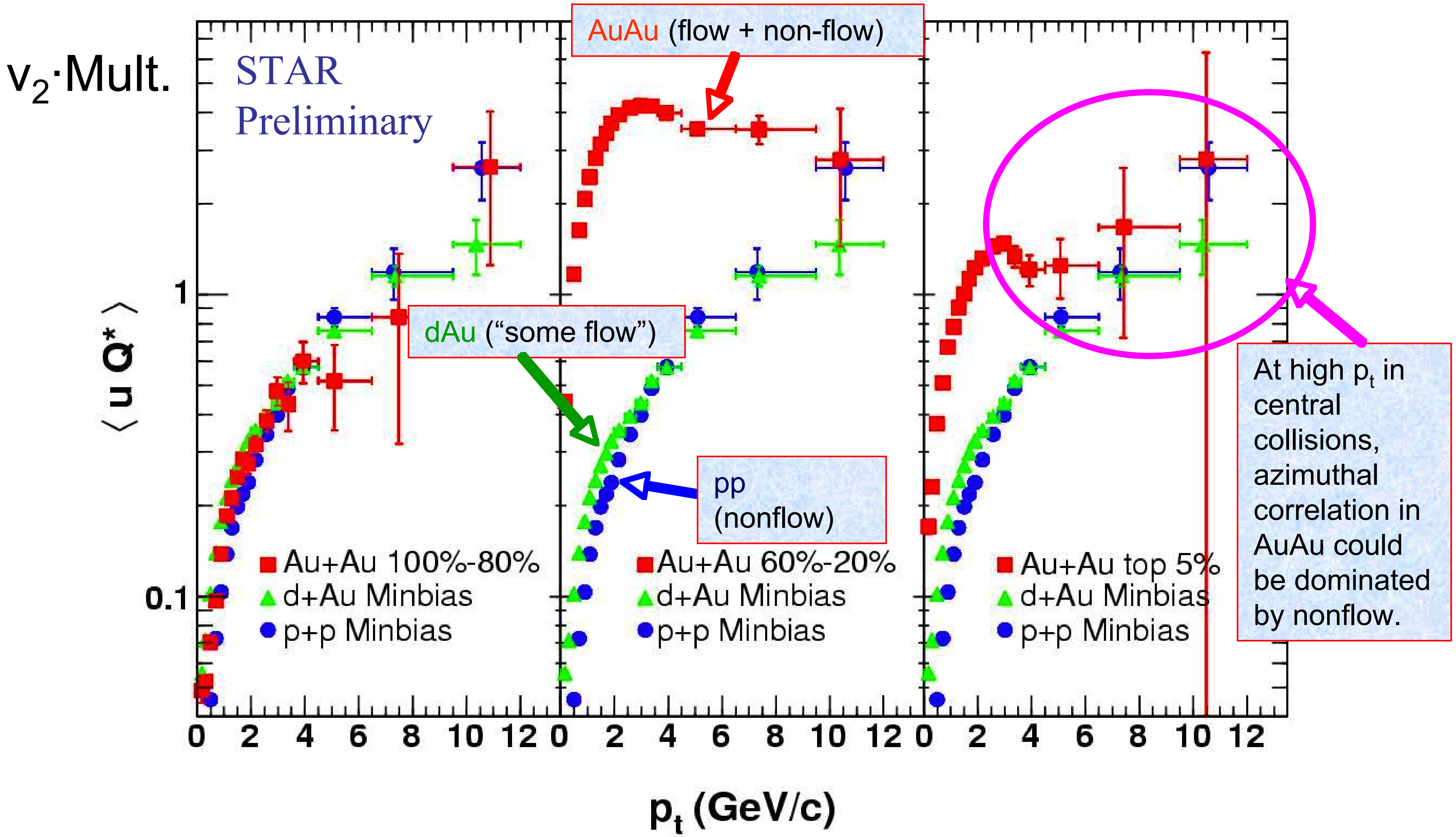
AZIMUTHAL CORRELATIONS FROM CGC

Kovchegov, KT 2002,2003



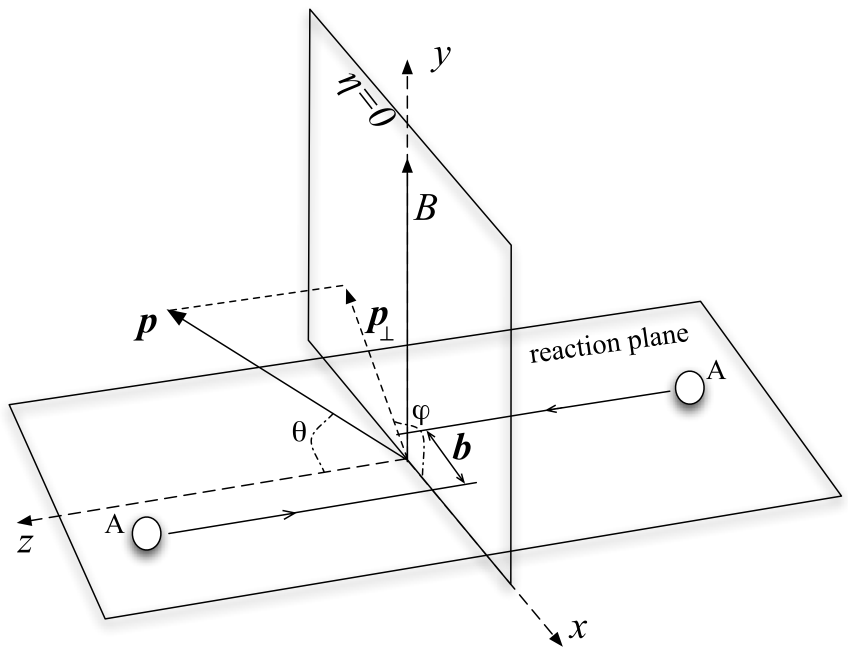
Mini-jet correlations in CGC

AZIMUTHAL CORRELATIONS



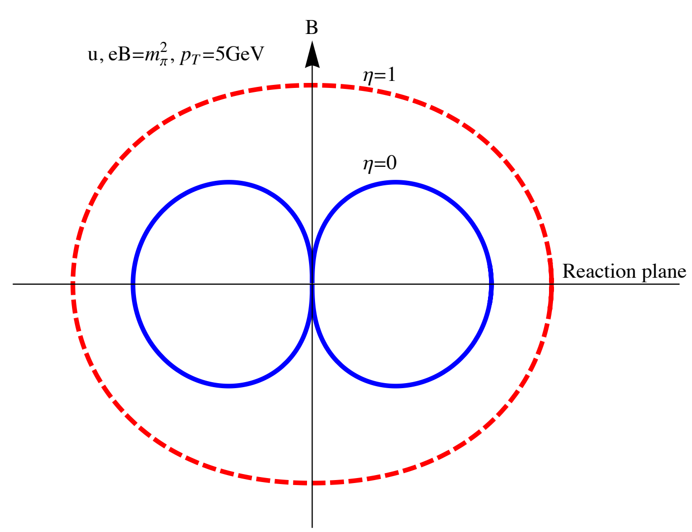
- Rapidity correlations → Kevin Dusling

STRONG MAGNETIC FIELD



- $eB \approx m_\pi^2 >> m_e^2$ → above the Schwinger's value!
- $B \approx$ const
- A fascinating opportunity to study the high intensity QED!

- E.g. strong B indices energy loss on fermions that can prevent light quarks from escaping the plasma (at LHC).
- This energy loss is azimuthally asymmetric - contributes to $\boldsymbol{v_2}$.



KT 2010

SUMMARY

1. High p_T, higher statistics measurements in dA will certainly help restrict CGC model parameters and allow better calibration of AA.

   - At high p_T CGC must agree with pQCD. What is the relevant scale?

2. R_{dA} at higher/lower energy is needed to resolve the role of fragmentation vs CGC.

3. J/ψ production mechanism remains as mysterious as ever. Measurements of ψ', χ_c, etc., polarizations and p_T spectra will certainly help.

4. Correlations in impact parameter space (diffraction), rapidity and azimuth (v_2) yield a lot of interesting information $\Rightarrow$ but must be calibrated in dA!

5. If existence of strong magnetic field B is experimentally confirmed, RHIC will be the first machine in the world to study the high intensity super-critical QED. Don't miss the opportunity!